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ABSTRACT

An overview is presented of the epistemology of the three types of constructivism. Criticized is another interpretation of constructivism; it is stated that this interpretation is trivial, cognitively abridged, and disrespectful of students' capacities, creativity, and imagination. Constructivism has to go beyond saying that knowledge is constructed, it has to specify the purposes and processes of knowing which are discussed. The processes of assimilation, accommodation, and equilibration and their constraints are described. Behaviorism is compared to constructivism in terms of knowledge, learning, and teaching. (KR)

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WHAT IS CONSTRUCTIVISM AND WHY ARE THEY ALL TALKING ABOUT IT?

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WHAT IS CONSTRUCTIVISM AND WHY ARE THEY ALL TALKING ABOUT IT?

> Science is knowledge of the genus or mode by which a thing is made; and by this very knowledge the mind makes the thing, because in knowing it puts together the elements of that thing
> (Vico, 1710/1988).

> We do not experience things; things are a construction of ours the function of which is to emphasize the resemblance between aspects of our present immediate experience and aspects of our past experience, something which proves enormously useful to do
> (Bridgman, 1936, emphasis his).

In professional meetings, one starts to hear expressions like "constructivism", "construction of knowledge", or "learners construct their own meaning in science". Browsing through the recent issues of two professional journals of Science Education (Science Education and Journal of Research in Science Teaching) one has the impression that "constructivism" has not yet filtered into the mainstream of professional literature. There are, however, some scattered references to ideas that could be interpreted as pointing in that direction.

As early as 1983, Lauren Resnick, published a short note about a new conception of learning in Science and Mathematics that was emerging from research in the field of cognitive science. She speaks about the new image of the learner in these terms: "...learners construct understanding. They do not simply mirror what they are told or what they read" [emphasis added]. Another article on the study of students'

errors in science (Fisher & Lipson, 1986) states its assumptions in the following terms:

> Several assumptions underlie research on errors and alternative conceptions. Among these are: Knowledge and thought involve active, constructive processes; there are many ways to acquire, organize, store, retrieve, and think about a given concept or event; and understanding is achieved by successive approximations (p. 783) [emphasis added].

While these examples may indicate a slow diffusion of some ideas the field of Science Education, as portrayed by the literature, seems fairly virgin of constructivist explorations. In a recent review of research perspectives in Science Education, Eylon and Linn (1988) do not refer to constructivism or constructivist research by those (or equivalent) names. Their silence may be due to the recency of the interest in the perspective, to the generalized lack of clear epistemological commitments of most research in Science Education, or to the way the authors chose to group the pieces reviewed. In any case, it seems that "constructivism" is not the first thing that comes to mind in reading, reviewing, or doing research in Science Education. Going through the list of the articles they reviewed there are two that seem to assume an explicit constructivist view. They come from British researchers connected with the Centre for Studies in Science and Mathematics Education at the University of Leeds (Arnold & Millar, 1987; Driver & Oldham, 1986).

To find out "what is meant by constructivism in Science Education" one has to go to the literature that comes from this group of researchers and from people they have influenced. This paper is not the place to make an exhaustive review of such literature. We will

content ourselves with analyzing in some detail a representative piece. The article by Driver and Bell (1986) is, to my knowledge, fairly representative, and being a conceptual piece provides some insight into the notion of "constructivism" held by the authors.

According to this paper a constructivist understanding of students' thinking in Science entails a different view of Science and a different view of the learning process (p. 443). In the constructivist view that Driver and Bell (1986) explain, the entities science talks about

> like electrons, force fields, etc. are not part of the world of sense impressions, they are not even abstracted from this world. They are imaginative constructions, themselves related in very precise ways, which are brought to bear on this world (p. 443-444).

Their view of Science is further elaborated with the comments on the following quote:

> Science is not just a collection of laws, a catalogue of facts it is the creation of the human mind with its freely invented ideas and concepts. Physical theories try to form a picture of reality and to establish its connections with the wide world of sense impressions (Einstein & Infeld, 1938 as quoted in Driver & Bell, 1986, p. 444).

In those comments the authors emphasize two points: 1) In Science, a distinction is made between "the world of sense impressions and that of ideas and concepts" (p. 444); 2) the relationship between sense impressions and theories is not direct (p. 444).

Explaining the distinction between sense impressions and concepts in Science the authors point that Karl Popper (1973), in his book Objective Knowledge goes a step further, distinguishing three worlds:

"the world of sense impressions, the world of individual constructions, and the world of the scientists shared constructions as documented in books and research reports" (Driver & Bell, 1986, p. 444).

The reference to Karl Popper's three worlds deserves to be clarified in order to understand some characteristics of Driver and Bell's (1986) constructivism that will become important later in this paper. Popper (1973) says:

> We may distinguish the following three worlds or universes: first, the world of physical objects or physical states; secondly, the world of states of consciousness, or of mental states, or perhaps behavioral dispositions to act; and thirdly, the world of objective contents of thought, especially the scientific and poetic thoughts and of works of art (p. 106, emphasis in the original).

The important thing to note here is that these three worlds are conceived in ontological terms. This means that Popper conceives the second and third worlds like the first as existing independently of any individual or collective mind (Popper, 1973; Popper & Eccles, 1977).

The second point that Driver and Bell (1986) elaborate from the quote of Einstein and Infeld

> concerns the nature of the relationship between sense impressions and theory. Concepts or theories do not follow from observations in a simple 'inductivist' way. We have all, no doubt, experienced the difficulties students have in 'abstracting' facts from the results of practical work. Although we may argue that the human mind may be constrained by many factors (including language and images current in society at the time), the act of theorizing, does involve an imaginative process of invention (p. 444, emphasis added).

Summarizing, we could say that for these authors science deals with two planes of experience (which they call different worlds) and that the relationship between them is at best problematic. They also

say that in relating these two planes, scientists use constructive and imaginative processes. They go on to suggest that this has immediate consequences for the learning of science. For them "learning takes place not only through the taking in of new information but also involves organization and imaginative restructuring of conceptions or frameworks that learners already have" (p. 444).

Stating their "constructivist view of learning" the authors start by criticizing "the common sense view of learning as absorbing knowledge" (p. 444, emphasis in the original). They say that "current perspectives suggest that learning involves an active process in which the learner is engaged in constructing meanings whether from text, dialogue, or physical experience" (p. 444). The elaboration of what this assertion means is done around six key ideas:

1) "Learning outcomes depend not only on the learning environment but on what the learner already knows: Students' conceptions, purposes and motivations influence the way they interact with learning materials in various ways" (p. 444);
2) "Learning involves constructing meanings" (p. 447); "Meanings constructed by students from what they see or hear may or may not be those intended; Construction of a meaning is influenced to a large extent by our existing knowledge" (p. 453)
3) "The construction of meaning is a continuous and active process" (p. 448);
4) Beliefs are crucial in the evaluation and acceptance of meanings (p.451);

5) "Learners are responsible for their own learning" (p. 452);

6) "There are patterns in the types of meanings students construct due to shared experiences with the physical world and through natural language" (p. 454).

Reading the authors elaboration of these key ideas there are three points that seem salient in their constructivist view of learning and deserve criticism:

1) Their view of science and learning is not as new or different as it purports to be. Even the most positivist of the positivist philosophers of science speak at length about the creative dimensions of the scientific undertaking. As to learning, John Locke in the seventeenth century speaks of ideas coming from the senses or from the mind reflecting on its own operations;

2) The authors use many times the expression "construction of meanings" or equivalent ideas but they do not make explicit neither the processes by which the construction takes place nor the results of such a construction. Moreover the status of these constructions in terms of truth or adequacy is not made explicit;

3) Throughout the article, students' own knowledge, concepts, and ideas are portrayed more as a hindrance than as the indispensable foundation for the construction of new knowledge. The authors seem to forget that a constructivist view of learning entails that without previous knowledge no learning of anything whatsoever is possible, beyond the level of elementary

reflexes. If the mind of the student is a tabula rasa no matter how much and how well we teach him/her it will remain a tabula rasa.

The view of constructivism presented by Driver and Bell (1986) is, therefore, trivial, cognitively abridged, and disrespectful of students' capacities, creativity, and imagination.

In order to make a viable meaning for constructivism and avoid the traps that the authors discussed fell into we have to retrace our steps from a plausible beginning. To begin with constructivism is a theory of knowledge. This means that it involves a conception of the knower (epistemic subject), a conception of the known (epistemic object), and a conception of the relation knower-known (epistemic relation). If we agree that learning is the acquisition of knowledge and that science is knowledge about certain experiential objects then constructivism includes a theory of learning and a theory of science but is not limited to either or both.

A constructivist epistemology as the name implies explicitly states that all knowledge we come to have is our own construction. In light of what has been said, this statement seems to be now a rather trivial one. Given that we cannot conceive of the world of experience entering our minds in one piece we have to assume that it must be constructed in some way. The implications of this realization are not, however, trivial at all. Constructivism denies the possibility of knowledge transmission, even in principle.

> From that perspective [constructivism] there is no way of transferring knowledge - every knower has to build it up for himself. The cognitive organism is first and foremost an organizer who interprets experience and, by interpretation, shapes it into a structured world. That goes for experiencing what we call sensory objects and events, experiencing language and others; and it goes no less for experiencing oneself. "L'intelligence organise le monde en s'organisant elle-meme" (1) (von Glasersfeld, 1982).

Knowledge ceases to be a commodity that can be transferred from the mind of a giver (e.g. a teacher) to the mind of a receiver (e. g. a learner). Saying that "learning takes place not only through the taking in of new information..." (Driver & Bell, 1986, emphasis added) in a constructivist view is either a slip of the tongue or a contradictory statement. Even if the givers intend their communications as a transmission, the concepts, ideas, text, etc. transmitted have to be interpreted (and in that sense constructed) by the receivers with elements of their experience (von Glasersfeld, 1983). The great surprise of most of the misconceptions in Science research that what teachers thought they taught bore little resemblance to what students understood (i.e. constructed) is no surprise at all for a constructivist. This idea is not even new as the following quote from Ludwik Fleck (1929/1986) shows:

> We forget the simple truth that what we are acquainted with consists rather of what we reach by learning than of what we arrive at by knowing. Yet this is a momentous fact, since in the short span from the teacher's mouth to the student's ear the content of the knowledge transmitted is always slightly distorted. Thus in the course of decades or even centuries and millenia, divergences develop to an extent that it sometimes becomes doubtful whether anything of the

(1) Intelligence organizes the world by organizing itself (Piaget, 1973, p. 311).

> original has been preserved at all. In the circumstances the content of knowledge is by and large a free creation of culture. It resembles a traditional myth (p. 47).

Constructivism to become a viable alternative to traditional (and entrenched) epistemologies has to go beyond saying that knowledge is constructed, it has to specify the purposes and processes of knowing.

The first question to be answered is the question of purposes: Why do we need to construct knowledge at all? The answer seems to be simple and straightforward: We need to construct knowledge in order to manage our experience. We should always be suspicious of simple answers. In epistemology (and life in general) simple answers are either false or hide a great deal of complexity. Manage our experience means in this context acting in such a way as to bring about desired results and avoid undesirable ones. In order to be able to do this we have to have some idea (no matter how rough and incomplete) of some of the possible results and how to choose between them (i.e. some valuing scheme). These expectations and preferences come from our previous experience. Trying to bring about our expectations (i.e. to repeat previous experiences) we construct working hypotheses (no matter how simple) of how things will behave when acted upon in certain ways. As long as these hypotheses are fulfilled by the results of our action (i.e. by our interpretations of what happens) we will continue to use them. They are our concepts, ideas, theories, models, images, etc. of how the world of our experience behaves. They constitute our understanding of the world, and serve as tools to be used in future situations.

This vision of the knowing activity entails a notion of the knower that is based on certain presuppositions about its minimal requirements:

> The ability and beyond that the tendency to establish recurrences in the flow of experience; this, in turn, entails at least two capabilities,
> - remembering and retrieving (re-presenting) experiences,
> - and the ability to make comparisons and judgments of similarity and difference;
> - apart from these, there is the presupposition that the organism likes certain experiences better than others, which is to say it has some elementary values (von Glasersfeld, 1989, emphasis added).

The next question to be answered by a constructivist epistemology is the question of processes: How do we come to know what we know? To answer this question, constructivism brings together the insights of Giambattista Vico (1644-1744), italian philosopher, humanist, and rhetorician, and the research of Jean Piaget (1896-1980), swiss genetic epistemologist. Vico, besides being a major figure of humanistic thinking, is considered by several scholars as a remarkable case of foreshadowing most of Piaget's important ideas (Mora, 1976a, 1976b; Gash, 1983; Gash & von Glasersfeld, 1978; von Glasersfeld, 1976a). Contemporary constructivists consider him as a forerunner (Gash & von Glasersfeld, 1978; von Glasersfeld, 1983, 1984, 1985, 1989). Piaget, also claimed by constructivists as one of them is well known (though not well understood) for his essential contributions to the theory and description of human knowing.

Referring to what it means to know (latin verb scire, root of science) Vico says that

> science is knowledge of the genus or mode by which a thing is made; and by this very knowledge the mind makes the thing, because in knowing it puts together the elements of that thing" (Vico, 1710/1988).

Piaget, two centuries later, expresses the same conception when he writes that

> knowing consists in constructing or reconstructing the object of knowledge in such a way as to grasp the mechanism of this construction; which is the same as saying (if one prefers to use the terms that positivism has persistently but ineffectually proscribed) that to know is to produce in thought (i.e. in the thinking mode), and the production must be such that it reconstitutes the way in which the phenomena are produced (Piaget, 1961, translated in von Glasersfeld, 1974).

The research and theorization of Jean Piaget and his collaborators informed by this conception constitutes the most extensive and detailed investigation of human knowing. Most of what follows (and some of what came before) is based on Piaget, or constructivist readings of his work (von Glasersfeld, 1974, 1976a, 1982, 1983, 1984, 1985, 1989).

Confronted with some experience we tend to use some concept or model, or pattern of action that past experience leads us to expect satisfactory results and act accordingly. If the results of our action are the expected ones (i.e. satisfactory according to our goals) the experience becomes for all purposes a case of the concept, model or pattern of action used. We call the concept, model or pattern a "scheme" and describe the inclusion in the scheme as "assimilation", borrowing Piaget's terminology. In doing this we focus more on the similarities we could compare and disregard differences, we

> engage in an act of judging, interpreting or bringing the object under a certain category. Hence, assimilation is the equivalent of a judgment: to assimilate a thumb to a sucking scheme is to judge the thumb as something to be sucked (Kitchener, 1987).

For all the purposes that matter, the thumb is "a suckable".

As soon as this and other assimilations are successfully made we tend to use the same scheme over and over again. The repeated use of a scheme has two consequences: 1) the scheme becomes more and more generalized and flexible (e. g. we generate different subsets of "suckables"); 2) sooner or later the use of schemes generates problems (e.g. a spoon may not lend itself to a sucking scheme very easily).

Problems arise when the results of our acting are not the ones we expected from previous experience. We may disregard the differences as unimportant and keep our scheme unaltered or judge the differences as important. In the last case we have a perturbation in our understanding of experience. This perturbation makes us become aware of our own cognitive activity in order to generate a new solution. The idea of awareness of our own cognitive functioning as fundamental for any cognitive change was considered a psychological law by the French psychologist E. Claparede and borrowed by Piaget who called it "prise de conscience" [grasp of consciousness] (Kitchener, 1987). The new solution needed is made by stepping back (so to speak) from our concepts, models, or patterns and try novel combinations (e. g. the spoon may be hit against something) until we are able to produce the expected results, other satisfactory results, or give up for the moment. The novel combination generated in the process is an altogether different model, concept or pattern. In the terminology of

Piaget, we say that the previous concept, model or pattern has been "accommodated". The two processes of assimilation and accommodation are never completely independent. In fact, Piaget conceives them as constituting "two poles, not two distinct behaviors" (1975). They are two poles of a single process that Piaget calls "equilibration".

Piaget assumes that in our search for solutions we tend to form cognitive structures (i.e. patterns of action, concepts, images, models, theories, etc.) that are in dynamic equilibrium. This dynamic equilibrium is a result of structures that are flexible enough to allow disregarding of differences but not so generalized that anything can be subsumed under them. If we do not disregard differences in some instances assimilation is not possible and no concept is formed (e.g. if for each dog we see we have to make different concept the concept of dog is of no use). If we disregard too many differences our conceptions are never changed and become ossified, hence useless (von Glasersfeld, 1976b). Cyberneticists know that an intelligent machine that does not disregard enough differences soon overloads its memory space and breaks down and one that disregards too many differences soon enters into infinite loops and breaks down also (Cellerier, 1968).

The two processes of assimilation and accommodation always take us to a state where our structures will be different (hopefully, more useful, interconnected, and elegant) than the previous state. The process of equilibration leads to a new equilibrium not to the same that there was. This is why Piaget called it "equilibration majorante" [optimizing or equilibration].

The process of equilibration allows our knowledge to change and at the same time to remain stable. We preserve and discard schemes in a non-random way. Another problem seems to arise here: How are schemes preserved and discarded? The answer to this question makes us introduce another important dimension of a constructivist epistemology: the evolutionary dimension.

A scheme (i.e. a concept, idea, theory or pattern of action) will be preserved in our repertoire if and only if it helps us deal with our experience. This does not mean that the piece of knowledge in question is the only possible solution to the problem confronting us. It means no more and no less that in using this solution we have not encountered any obstacles to the obtainment of the results we expect. The solution has passed the constraints of experience and has thus proved viable. In a constructivist epistemology there is not one right solution but there are clearly wrong (i.e. unviable) ones. A solution that encounters constraints that it cannot pass has to be modified (i.e. remade) to pass them or dropped as useless (von Glasersfeld, 1984, 1985). The analogy with a neo-darwinist concept of adaptation is clear here.

Adaptation in neo-darwinist conceptions of evolution ceased to have teleological connotations. If adaptive modifications are the result of random variations in the genetic pool of a population we cannot say that organisms (or populations) adapt themselves to the environment (unless we want to use a misleading metaphor). Environmental constraints select out those organisms that do not have the necessary genetic make-up to pass them and leave the others. At

any time the organisms that survive are not those which adapted themselves but those that the constraints of the environment have left. Organisms (and populations) either fit the environmental constraints and survive or they do not and die (von Glasersfeld, 1980a, 1980b, 1985). Our knowledge can be conceived in much the same way. The schemes we possess either pass the constraints of experience and prove viable or do not and we discard them (von Glasersfeld & Cobb, 1983).

Our knowledge, to use an image of von Glasersfeld (1984, p.21) fits our experience as a key fits a lock. The key enables us to open the lock but tells us very little (if anything) about the lock. We all know that different keys can open the same lock. Worst even is the fact that burglars use a picklock, a very simple tool, to open different kinds of locks. Our knowledge may have very little relation with the reality underlying our experience and we cannot assume a one-to-one relationship (i. e. a match) between the two. There is no way of even assessing that relationship given that to compare our knowledge with "reality" we would have to perform another act of knowing and never access reality-in-itself (i.e. before any act of knowing). This paradox inherent to any act of knowing that purports to know things-in-themselves was pointed already by the Sophists, especially Gorgias of Leontini (c. 440 B.C.) and erected into a fundamental objection to the possibility of any certain knowledge by the Sceptics of the New Academy, especially Carneades of Cirene (c.213-129 B.C.) (Bury, 1933).

The seriousness with which different constructivist epistemologies take this paradox allows us to distinguish three types of

constructivism:

1) Radical constructivism, if the relationship between knowledge and "reality" as a criterion of truth has been abandoned and substituted by a criterion of fitness:

> Radical constructivism, thus, is radical because it breaks with convention and develops a theory of knowledge in which knowledge does not reflect an "objective" ontological reality, but exclusively an ordering and organization of a world constituted by our experience (von Glasersfeld, 1984, p. 22, emphasis in the original).

Piaget's epistemology, according to some interpretations (von Glasersfeld, 1974, 1982) is compatible with radical constructivism.

2) Hypothetical realism if our knowledge (especially scientific knowledge) is considered an hypothesis about the structure of reality and evolving assymptotically to a perfect (though unattainable) knowledge of that reality (Munevar, 1981):

> The forms and categories of conceptualization are also functions of central nervous organization, which bear an analogy-relationship to the inherent reality of objects which is just as incomplete as the relationship between the color "red" and the electromagnetic waves of a given range of wavelengths (Lorenz, 1971, quoted in Munevar, 1981).

Lorenz, Popper and most evolutionary epistemologists can be interpreted as belonging here. Piaget, according to Kitchener (1987), also belongs here.

3) Trivial constructivism if our knowledge is considered as a constructed picture of the reality of things-in-themselves. In its most flagrant cases trivial constructivism results from not taking a constructivist position to its consequences.

> Because it seems clear that the world cannot enter into a cognitive organism's domain all in one piece, most cognitive scientists today would agree that knowledge has to be "constructed". [...] As it happened, however, many who adopted the conception of an actively constructing organism did not and do not pursue the implications such a change of view has for the commodity that goes under the name of "knowledge". In fact, these new "constructivists" do not push much further than John Locke who, three hundred years ago, stressed the importance of the operations of the mind that produce complex ideas. But less conscientious than he, the present-day empiricists don't seem to acknowledge what the sceptics have been telling us ever since the Pre-Socratics: namely that there is no logically feasible way of checking the 'objective truth" of knowledge if the object of that knowledge is accessible only through yet another act of knowing. From an epistemological point of view, therefore, much of what now claims to be "constructivism" is trivial (von Glasersfeld, 1985, emphasis added).

Evolutionary analogies come into constructivism to answer two questions: the question of purposes and the question of processes. We construct knowledge because that has proved adaptive in the course of our evolution as a species. In the process of construction (which includes use) our schemes are preserved or discarded (analogy with survival) if they pass or not the constraints of our experience. Given that the constraints of experience can never be known in advance, the importance of creativity and multiplicity of ideas cannot be overstressed. Some contemporary philosophers of science apply this idea to science itself and say that the coexistence of different, even competing paradigms is a desirable feature (e.g. Feyerabend, 1975; Naess, 1972).

The introduction of evolutionary dimensions into constructivism leads to another problem: What are these constraints our schemes have to fit and where do they come from? Constraints, in a cognitive sense,

can be generally conceived as the elements of experience that do not fit our expectations and thus prevent us from achieving the results we intend. We may distinguish four sources of constraints:

1) the elements of our previous constructions;

2) other cognitive organisms;

3) the domain of our experience;

4) the total network of cognitive structures that form our knowledge at any given time;

These are the four selecting devices that make us preserve, discard or modify our cognitive structures. The four sources of constraints are distinguished above for purposes of clarity of analysis not because they are distinct. Given their crucial role in the construction of knowledge they deserve a more detailed look.

The characteristics of our previous constructions impose certain limitations to our future conceptualizations. The elements we abstract from the flow of experience, the ways we combine them, and the regularities we impose on them condition our subsequent ways of knowing and perceiving. As soon as infants achieve some notion of object permanence they populate their experience with "real objects". The construction of an euclidean notion of space makes us perceive the world in a certain way. To use another image of von Glasersfeld, building with bricks allows us to make certain kinds of constructions but not others (1984, p. 37).

Among the permanent objects we populate our experiential world with, there is a class that very early in our cognitive history becomes

extremely important for subsequent knowing. In our transactions with these "objects" we soon attribute to them properties we have attributed to ourselves. The process is reversible, because we come to attribute to ourselves properties that we had constructed to explain their behavior. This class of "objects" is composed of cognitive organisms (especially humans) that we come to conceive as having feelings, thoughts, etc. similar to ours (von Glasersfeld, 1985, pp. 97-98; 1986; 1989, pp. 10-12). Once these cognitive organisms are abstracted from the flow of experience (i.e. very early) they become an important source of constraints. In our interaction with them their behavior (especially symbolic) may or may not corroborate our previous conceptions. We all have experienced sometimes how a disagreement with someone may make us revise our notions, the concept of that person we have, or both. Another way in which other persons are crucial for knowledge construction is in provoking our awareness of inadequacies in our concepts. Called on to explain what we mean we may stumble in our own obstacles and generate the "grasp of consciousness".

Another set of constraints seems to come from the domain of our experience. There is a sense in which our experience albeit being our construction does not bend itself to our imagination, desires or goals. A constructivist can never say like the idealist "The world is my dream". Whenever our experience does not confirm our expectations we may have touched on the reality underlying it. The constraints we are encountering may come from that reality. They can only tell us, however, what that reality is not. They leave open infinite possibilities for what it may be. In this sense, constructivism, like

idealism, maintains that we are cognitively isolated from the "nature of reality". By maintaining this, constructivism does not deny the existence of a "real world" (i.e. a world independent of any knower) but merely the possibility of our cognitive access to it. In doing this constructivism abandons the correspondence between our knowledge and "real world" as a criterion for truth with the logical and empirical paradoxes it entails (von Glasersfeld, 1989). The criterion has become one of adequacy or fitness.

The last set of constraints our constructions have to pass comes from the realization that none of our cognitive structures makes any sense in isolation. Concepts, ideas, images, theories, etc. are related with each other. This does not mean that our knowledge is at any time a completely consistent system. It is a conceptual ecology (Toulmin, 1972). Any new piece of knowledge must also fit this conceptual ecology. Another consequence of this set of constraints is that we will tend to preserve the stability of the conceptual ecology. This means that our assimilations and accommodations must not cause perturbations that disrupt the whole ecology. If anything was gained with the research on misconceptions was the notion of how stable conceptual ecologies are even when submitted to the barrage of authority that goes by the name of "conceptual change teaching".

The detailed look we gave to the constraints that select our concepts, ideas, etc. poses a last problem: In what situations do these sets of constraints become important? This is equivalent to asking: In what kind of situations are changes in our knowledge more probable?

Any situation where we are "forced" to become aware of our cognitive functioning and look at our concepts, ideas, etc may provoke changes in our knowledge. For purposes of analysis we may distinguish four contexts where this change is possible:

1) a context of action;

2) a context of sense making;

3) a context of explanation; and

4) a context of justification.

Whenever we have to act purposefully and thoughtfully we may gather our conceptual resources to analyze the situation and act more effectively. This gathering of resources may make us aware of gaps and inconsistencies in our knowledge and start a process of construction (or reconstruction).

Sometimes our acting does not attain the results we expect or sometimes an unexpected event happens even without our action. In any of these cases in order to make sense of what happened we have to use our ideas, concepts, etc.. If this proves inadequate or unsatisfactory the process of construction may start.

The questions "What do you mean by...?", "How can you explain such and such...?" addressed to us by someone may provide another opportunity to become aware of our ideas. In trying to explain them we may make new relations or find inconsistencies. The process of change may start.

The last context of construction is justification. Having to defend our ideas we have no other choice than to become aware of them. Moreover the criticism of others may point to gaps or contradictions

that we never noticed. This may start a reconceptualization process.

Summarizing we can say that "constructivism is the view that reality itself is constructed by the epistemic subject" (Kitchener, 1987, p. 101). This definition entails two important consequences:

1) "knowledge is never a simple copy of reality, but always results from a construction of reality through the activities of the subject" (Inhelder, 1977, p. 339);

2) "...the subject constructs the cognitive schemes, categories, concepts, and structures necessary for knowledge" (Kitchener, 1987, p. 102).

The overview of constructivism given in the previous pages makes clear that we are very far from behaviorism. Let us, however, summarize some differences around the notions of knowledge, learning and teaching.

Behaviorism conceives knowledge as the passive accumulation of S-R bonds reinforced by the environment. Constructivism conceives knowledge as the activity of the knower that explores the possibilities of the environment. Knowledge for behaviorism is static while constructivism conceives it as a process of becoming. Some knowledge may be acquired by association but as soon as that happens constructive processes start and we are far beyond S-R bonds. Another difference is that constructivism postulates a knower that has not only a mind but also intentions things that are unknown in behaviorism. In behaviorism the epistemic relation is determined by the environment while constructivism conceives it as constrained only.

What was said for knowledge can be applied mutatis mutandis to learning. We must stress that for constructivism the learner is not only active but also maker of his own knowledge. The four contexts of knowledge construction become crucial learning environments.

Teaching in behaviorism is reduced to engineering the environment in order to reinforce the desired learnings and extinguish the undesired ones. In constructivism, teaching is conceived as participating with the students in the adventure of knowing. Teaching is not transmission but acting, making sense, explaining, asking explanations, criticizing, and justifying. In one word teaching becomes a form of learning.

The recent attention that constructivism is receiving from Science Educators seems to entail a paradox. The work of Piaget is one of the major sources of this view. What justifies then the claim of novelty given the Piagetian movement in science curriculum in the 60s? The paradox is apparent. Piaget was assimilated without accommodation by most of the curriculum developers of the sixties. This made them de-emphasize the epistemological novelty and difficulty of Piaget's ideas. Piaget was read and understood (i.e. misread and misunderstood) within a behavioristic framework. His stages of development were objectified into predictive instruments of what students could and could not do. Curriculum was developed to match these limits instead of challenging students' minds. The tasks he devised to study children's ways of knowing and conceived by him as means became ends in themselves and students were trained in them. Emptied of the epistemological underpinnings the thoughtful activity conceived by

Piaget as fundamental for construction of knowledge becomes meaningless activism (i.e. doing things just to keep "them" busy) taken to pitiful extremes in the implementations of the so-called "hands-on science". The belief that students will construct knowledge given the proper activities did not pay attention neither to the problem of constraints nor to the proper contexts of knowledge change.

The overview given of what a viable constructivism looks like places Piaget in a completely different light. Emphasizing his theoretical notions hopefully serves as contrast and will make us more careful in hasty readings (i.e. applications) of his insights.

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